Squeeze Film Damping in Microsystems

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Abstract:
Squeezed film damping (SFD) is a common phenomenon that occurs in many microdevices when a surface moves normally to another solid surface in close proximity. In microelectromechanical systems (MEMS), SFD is often one of the largest sources of parasitic losses. Therefore, an accurate evaluation of hydrodynamic forces due to the SFD effect is critical in the design and optimization of the MEMS. In this work, experiments are implemented to investigate SFD effects on the dynamic response of a micro-plate compared to theoretical solutions. The test specimen is fabricated using standard microfabrication techniques.

Summary of Research:
In the recent past, a few studies have attempted to quantify the damping coefficient associated with beams and plates oscillating in a fluid environment, however, most of them show discrepancies from classical hydrodynamic lubrication theory in the relationship between damping coefficient and gap height [1-5]. The objective of this work is to identify the reasons for these discrepancies. To achieve this goal, SFD effects were first theoretically investigated employing a dynamic system consisting of a micro-plate separated from a parallel substrate by a thin fluid layer and undergoing normal oscillations. A compact expression for hydrodynamic forces was developed by employing the classical perturbation theory for small Reynolds number [6]. To validate the theoretical results, experiments were designed to investigate the same dynamic system.

The schematic of experimental setup is shown in Figure 1. The micro-plate is clamped together with spacers on a polycarbonate substrate. The gap between the plate and substrate can be varied by adjusting the number of thin glass spacers. A piezo stack, which provides the vibration motion, is glued on the bottom surface of the substrate. The piezo stack is actuated by a sinusoidal voltage signal generated by a lock-in amplifier. The lock-in amplifier serves as a function generator here and the signal is then amplified by a linear piezo amplifier which is connected with the piezo stack. The entire set up is mounted on an optical table. The motion of the plate is measured by a laser Doppler vibrometer. Usually, for a fixed input voltage, the measurement starts with a small frequency (e.g., 200 Hz) which will then be increased gradually until the resonance is found and amplitudes in each step is recorded.

The vibrating micro-plates were fabricated via a single mask lithography process that starts with a <100> double-side polished silicon wafer with thickness 400 µm; 2 µm of silicon dioxide was thermally grown on both sides of the wafer. After photolithography, the pattern was then transferred to silicon dioxide layer by reactive-ion etching (RIE). The Si wafer was etched using deep reactive-ion etching (DRIE) and back side silicon dioxide acted as an etch stop. Finally, a buffered oxide etching (BOE) 6:1 etching is performed to release the plate structure by etching the silicon dioxide layers. The thickness of the silicon wafer determines the thickness of the vibrating plate and beams. The plate size is chosen to be 1000 µm × 1000 µm square and the width of the beams is 1/20 ~ 1/5 of the plate’s width.

Figure 1: Schematic experimental set up.
The length of the beams can be varying from two to five times longer than plate’s length. Several dozen vibrating plates were fabricated per wafer and each wafer was diced into chips of $25 \times 20 \text{ mm}^2$ with one plate per chip. Figure 2 gives the SEM image of one of the chips.

The preliminary results of the experiments tested in air are presented in Figure 3. It is shown that by reducing the gap from 50 $\mu$m to 30 $\mu$m, the resonant frequency shifts to the left and amplitude reduces. It is because both viscous damping and fluid inertia have inverse relationships with the gap; therefore reducing the gap will increase both the inertia and viscous forces. While viscous damping effects reduce the magnitude of the system, fluid inertia acts as an added mass, shifting the natural frequency of the system to a lower range.

For the future, we will continue the experimental measurement and test structure with different areas, beam widths in various media.

References:


